HIGH ENERGY CONTAINMENT DEVICE AND TURBINE WITH SAME

BACKGROUND OF THE INVENTION

1) Field of the Invention

The present invention relates to a device for containing material released by or into a rotary device such as a turbine.

2) Description of Related Art

Many rotary devices include a surrounding structure for containing fragments that are released by the device during a failure. For example, a conventional rotary device such as a flywheel has a housing that surrounds the flywheel. The housing can be a strong, rigid structure designed to withstand the impact of pieces, or fragments, of the flywheel that are released if the flywheel breaks while operating at a high rotational speed. Due to the high speed and/or mass of conventional rotary devices, the fragments released during failure can have significant kinetic energy. Therefore, the housing must be strong in order to contain the fragments, typically requiring a thick housing that adds weight and cost to the device.

U.S. Patent No. 6,182,531, titled "Containment Ring for Flywheel Failure," which issued February 6, 2001, describes a containment vessel that includes an outer ring with a plurality of inner shaped elements that produce an inner ring layer. The inner shaped elements are juxtapositioned axially along the inner periphery of the outer ring and configured to produce hollow cells that plastically deform to absorb the energy from an impact of a high energy material fragment, such as are produced during catastrophic failure of a flywheel. The inner shaped elements are configured to deform at a sufficiently fast rate to prevent the inner shaped elements from rupturing or buckling.

An increased likelihood of piercing or otherwise damaging a housing or containment vessel exists where the rotary device has sharp edges extending radially outward. However, even where the rotary device does not have sharp outer edges, sharp edges can be formed if the rotary device fails. For example, typical flywheels

that are used for energy storage often fail by breaking into three segments. Each segment, which can have sharp edges at the point of breaking, typically rotates as the segment moves radially outward. The rotation and path of travel of each segment are determined in part by the speed of the flywheel, the material of the flywheel, the size of the segment, and the location of the center of mass of the segment. The housing or other containment vessel for a flywheel is typically located near the flywheel, as illustrated in the figures of U.S. Patent No. 6,182,531. Thus, only limited rotation of the segments can occur before the segments collide with the housing, thereby limiting the possibility that the broken edges of the segments will contact the housing. On the other hand, if the housing or other containment vessel is located some significant distance from the flywheel or other high energy rotary device, piercing and other damage is more likely to occur.

Thus, there exists a need for an improved containment device that can contain materials released by or into a rotary device, and a rotary turbine with such a containment device. The containment device should be able to contain materials with significant kinetic energy. Further, the containment device preferably should reduce the likelihood of piercing or other damage that results from materials that define sharp edges or points.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a containment device for use in retaining debris material traveling radially outward in a rotary device such as a turbine. The containment device includes an outer ring that extends generally circumferentially and a plurality of energy absorption elements disposed on an inner surface of the outer ring. Each absorption element extends radially inward and circumferentially and is configured to be plastically deformed radially outward (and axially once radial deformation has occurred) by debris material impacting the absorption element. Further, each absorption element can be formed of a base and a cap, the base extending generally radially inward from the outer ring and the cap being connected to the base and defining an angle therebetween.

According to one embodiment of the invention, each absorption element extends circumferentially to at least partially overlap an adjacent one of the absorption elements. The cap of each absorption element can extend circumferentially at least to overlap the first end of the cap of an adjacent one of the absorption elements.

According to one aspect of the invention, the angle of each base, relative to a tangential direction of the outer ring, is between about 35 and 95 degrees, and the angle of the cap relative to the tangential direction is between about 0 and 45 degrees.

Each absorption element can extend generally in an axial direction of the outer ring. In addition, the absorption elements can be formed of carbon steel, stainless steel, or Inconel®, and the caps, which can be thicker than the bases, can be welded thereto. Further, according to one aspect of the invention, the distance between the absorption elements, e.g., the caps, and an arc defined by the outermost edge of a rotating element therein, is at least about 1/10 of the diameter of the rotating element.

The present invention also provides a turbine with a containment device for containing debris material. The turbine includes a rotatable turbine rotor configured to rotate about an axis of rotation and at least one turbine blade connecting to the turbine rotor and configured to rotate about the axis of rotation with the turbine rotor. The containment device can include an outer ring and a plurality of absorption elements, as described above. The absorption elements can be substantially parallel and extend generally in the axial direction of the rotor, and the outer ring and the absorption elements can be longer in the axial direction than the rotor and blades.

Thus, the containment device of the present invention can contain debris released by or into a rotary device, including such materials having high kinetic energy. In addition, the containment device reduces the likelihood of piercing or other damage that results from debris that defines sharp edges or points.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

Figure 1 illustrates an elevation view of a containment device according to one embodiment of the present invention;

Figure 2 illustrates a perspective view of the containment device of Figure 1;

Figure 3 illustrates an enlarged partial view of the containment device of Figure 1; and

Figure 4 illustrates a gas turbine with three turbine stages, each having a containment device according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

Referring now to the figures and, in particular, Figures 1 and 2, there is shown a containment device **10** for retaining structural fragments, foreign objects, and other material, referred to generally as debris material, traveling from or through a rotary device **12**. The containment device **10** of the present invention can be used with a variety of rotary devices **12**. For example, the rotary device **12** can be an energy storage unit, a transmission, a gearbox, a turbine, or another rotary device that includes at least one rotatable element **40** such as a flywheel, gear, or turbine rotor **42** with blades **44** extending therefrom, as shown in Figures 1 and 2. The rotary device **12** can also include other structural members that do not rotate with the rotatable element **40**. The debris material can include structural fragments that are broken from the rotatable element **40** during a failure of the rotary device **12**. Alternatively, the debris material can be a foreign object that travels through the rotary device **12**, such as part of a tire or a piece of structural material from an airplane that is drawn into a turbine of a jet engine on the airplane. The debris material can have substantial mass and/or velocity and, hence, high kinetic energy.

The containment device **10** includes an outer ring **14** that defines an inner surface **16** directed radially inward. Disposed on the inner surface **16** is a plurality of energy absorption elements **18**. The absorption elements **18** can define a variety of shapes and sizes, but each absorption element **18** extends generally radially inward. For example, as shown in Figure 1, each absorption element **18** has a base **20** and a cap **30**, which can be welded or otherwise connected. The base **20** extends generally radially inward, for example, at an angle relative to the radial direction of the outer ring **14**. A first end **22** of the base **20** is connected to the outer ring **14**. Each cap **30** is attached to a second end **24** of the respective base **20** so that the cap **30** is cantilevered from the base **20** and defines an angle with the base **20**.

Thus, the absorption elements **18**, which include the bases **20** and caps **30**, extend radially inward and also in the circumferential direction of the outer ring **14**.

By the term "circumferential direction," it is meant that each of the absorption elements **18**, e.g., the caps **30** thereof, extend at least partially in a direction perpendicular to the radial direction of the outer ring **14**. The absorption elements **18** are also configured in size, shape, and location so that each absorption element **18** overlaps at least one of the absorption elements **18** proximate thereto. As illustrated, the base **20** and cap **30** are generally flat members, i.e., plates, as illustrated in Figures 1 and 2, and each base **20** and cap **30** extends substantially in an axial direction of the outer ring **14**.

The absorption elements **18** are formed of a material that has sufficient strain energy capability so that the absorption elements **18** can be plastically deformed, or bent, by material that travels radially within the outer ring **14** and collides with one or more of the absorption elements **18**. Preferably, the absorption elements **18** are configured to deform at a rate fast enough to prevent localized failure, as is described in U.S. Patent No. 6,182,531 to Gallagher, the entirety of which is incorporated herein by reference. For example, the absorption elements **18** can be formed of steel, such as carbon steel, stainless steel, or a nickel-chromium-iron alloy such as those belonging to the Inconel® family of alloys, a registered trademark of Huntington Alloys Corporation. The bases **20** and caps **30** can be formed of the same or different materials, and each can have a different size and thickness. For example, each base **20** can be configured to plastically deform to absorb the energy of impact of debris material, and each cap **30** can be configured to resist shear failure so that the debris material does not pierce the caps **30** and travel through the outer ring **14**. Preferably, the bases **20** and/or the caps **30** are configured to prevent debris material from piercing the containment device **10** and traveling through the outer ring **14** thereof. For example, the caps **30** and bases **20** can be formed of the same material, with each cap **30** having a greater thickness than the respective base **20** so that the cap **30** prevents debris material from piercing the containment device **10**. The absorption elements **18** can also be configured so that if an absorption element **18** is sufficiently deformed by debris material, the absorption element **18** contacts at least one other absorption element **18**, thereby spreading the load associated with the debris material over multiple absorption elements **18**. The outer ring **14**, which can be formed steel or other materials, is preferably sufficiently rigid to support the absorption elements **18** while the absorption elements **18** contain debris material therein. However, the outer ring **14** can alternatively be configured to deform to contain debris.

As shown in Figure 3, the base **20** of each absorption element **18** can be configured at an angle β, relative to the tangential direction of the outer ring **14** where the base **20** connects to the outer ring **14**. Each cap **30** can be configured at an angle α relative to the same tangential direction. According to one embodiment of the present invention, the angle β is between about 35 and 95 degrees, and angle α is between about 0 and 45 degrees. A midpoint of the cap **30** can be connected to the base **20** so that the cap **30** extends equidistant in opposing directions from the base **20**. Thus, each cap **30** can define first and second ends, each of which are cantilevered from the respective base **20**, and the first end of each cap **30** can extend circumferentially to overlap the second end of the cap **30** of an adjacent absorption member **18**. Alternatively, each base **20** can be connected to other portions of the respective cap **30** so that the cap **30** extends a greater distance on one side of the base **20** or even extends in only one direction from the base **20** to form an L-shape with the base **20**. Further, one or both of the cap **30** and base **20** of each absorption element **18** can be curved. For example, a curved cap **30** can extend from a generally flat base **20** so that the absorption element **18** defines a hooked or J-shaped member. In any case, the absorption elements **18** can collectively extend continuously circumferentially inside the outer ring **14** to receive debris material that travels radially outward toward the outer ring **14**.

Figure 4 illustrates part of a gas turbine **50**, such as an auxiliary power unit, that has three turbine stages **52a**, **52b**, **52c** with containment devices **60a**, **60b**, **60c**. Containment devices according to the present invention can also be used for other turbine devices, such as for the turbines or compressor stages of a jet engine. Each turbine stage **52a**, **52b**, **52c** illustrated in Figure 4 includes a turbine rotor **54a**, **54b**, **54c** and a blade **56a**, **56b**, **56c**. The rotors **54a**, **54b**, **54c** and blades **56a**, **56b**, **56c** are rotatably mounted in the turbine **50** so that each rotor **54a**, **54b**, **54c** and blade **56a**, **56b**, **56c** can be rotated as air and combustion gases are moved axially through the turbine **50**. Each containment device **60a**, **60b**, **60c** includes a plurality of absorption elements **62a**, **62b**, **62c**, such as those described above in connection with Figures 1-3, disposed on an outer ring **64a**, **64b**, **64c**. Alternatively, each absorption element **62a**, **62b**, **62c** can be formed of a single flat plate, a curved plate that defines an S-shape or other curves, or other configurations.

The containment devices **60a**, **60b**, **60c**, including the absorption elements **62a**, **62b**, **62c**, can have a length in the axial direction that is longer than the rotor **54a**,

54b, **54c** and/or the blade **56a**, **56b**, **56c** of the respective turbine stage **52a**, **52b**, **52c** so that debris material produced by the fragmenting of one of the turbine stages **52a**, **52b**, **52c** is likely to travel radially outward and impact with the respective containment device **60a**, **60b**, **60c**. Further, as debris material impacts with the containment device **60a**, **60b**, **60c**, the absorption elements **62a**, **62b**, **62c** are deformed radially and axially. The deformed elements **62a**, **62b**, **62c** can at least partially receive the debris material, thereby restraining the debris from moving axially.

In some embodiments of the present invention, the containment devices may not be located immediately proximate to the outer edge of the rotating element in the rotary device. For example, the positions of the containment devices **60a, 60b, 60c** in Figure 4 are determined, in part, according to the operation of the gas turbine **50**. In particular, the distance between the absorption elements **62a**, **62b**, **62c** and an arc defined by the outermost edge of the rotating element, i.e., the turbine blades **56a**, **56b**, **56c**, can be greater than about 1/10 of the diameter of the respective rotating element. The distance between each turbine blade **56a**, **56b**, **56c**, or other rotating element, and the respective containment device **60a**, **60b**, **60c** can be sufficient for a portion of debris material that breaks from the rotating element to partially rotate before contacting the containment device **60a**, **60b**, **60c**, thereby potentially directing a sharp, broken edge toward the containment device **60a**, **60b**, **60c**. Advantageously, the absorption elements **62a**, **62b**, **62c**, e.g., the caps and/or bases thereof, can be sufficiently strong to resist piercing or other severe damage by the debris material, as described above.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.